The Basics of Solar Power:

Using solar power to produce electricity is not the same as using solar to produce heat. Solar *thermal* principles are applied to produce hot fluids or air. *Photovoltaic* principles are used to produce electricity. A solar panel (PV panel) is made of the natural element, silicon, which becomes charged electrically when subjected to sun light.

Solar panels are directed at solar south in the northern hemisphere and solar north in the southern hemisphere (these are slightly different than magnetic compass north-south directions) at an angle dictated by the geographic location and latitude of where they are to be installed. Typically, the angle of the solar array is set within a range of between site-latitude-plus 15 degrees and site-latitude-minus 15 degrees, depending on whether a slight winter or summer bias is desirable in the system. Many solar arrays are placed at an angle equal to the site latitude with no bias for seasonal periods.

This electrical charge is consolidated in the PV panel and directed to the output terminals to produce low voltage (<u>D</u>irect <u>C</u>urrent) - usually 6 to 24 volts. The most common output is intended for nominal 12 volts, with an effective output usually up to 17 volts. A 12 volt nominal output is the reference voltage, but the operating voltage can be 17 volts or higher much like your car alternator charges your 12 volt battery at well over 12 volts. So there's a difference between the reference voltage and the actual operating voltage.

The intensity of the Sun's radiation changes with the hour of the day, time of the year and weather conditions. To be able to make calculations in planning a system, the total amount of solar radiation energy is expressed in hours of full sunlight per m^2, or Peak Sun Hours. This term, Peak Sun Hours, represents the average amount of sun available per day throughout the year.

It is presumed that at "peak sun", 1000 W/m^2 of power reaches the surface of the earth. One hour of full sun provides 1000 Wh per m^2 = 1 kWh/m^2 - representing the solar energy received in one hour on a cloudless summer day on a one-square meter surface directed towards the sun. To put this in some other perspective, the United States Department of Energy indicates the amount of solar energy that hits the surface of the earth every +/- hour is greater than the total amount of energy that the entire human population requires in a year. Another perspective is that roughly 100 square miles of solar panels placed in the southwestern U.S. could power the country.

The daily average of Peak Sun Hours, based on either full year statistics, or average worst month of the year statistics, for example, is used for calculation purposes in the design of the system. To see the average Peak Sun Hours for your area in the United States, you can click the following link which will open a new window - just close it [X] when you're done to return here; **U.S.-Solar Insolation**

Choose the area closest to your location for a good indication of your average Peak Sun Hours.

For a view of global solar insolation values (peak sun-hours) use this link: **Global Peak Sun-hour Maps** , then, you can use [back] or [previous] on your browser to return right here if you want to. So it can be concluded that the power of a system varies, depending on the intended geographical location. Folks in the northeastern U.S. will need more solar panels in their system to produce the same overall power as those living in Arizona. We can advise you on this if you have any doubts about your area.

Components used to provide solar power:

The four primary components for producing electricity using solar power, which provides common 120 volt AC power for daily use are: Solar panels, charge controller, battery and inverter. Solar panels charge the battery, and the charge regulator insures proper charging of the battery. The battery provides DC voltage to the inverter, and the inverter converts the DC voltage to normal AC voltage. If 240 volts AC is needed, then either a transformer is added or two identical inverters are series-stacked to produce the 240 volts.

Solar Panels:

The output of a solar panel is usually stated in watts, and the wattage is determined by multiplying the rated voltage by the rated amperage. The formula for wattage is VOLTS times AMPS equals WATTS. So for example, a 12 volt 60 watt solar panel measuring about 20 X 44 inches has a rated voltage of 17.1 and a rated 3.5 amperage.

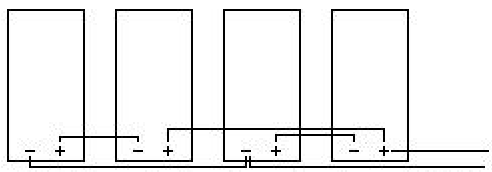
V x A = W

17.1 volts times 3.5 amps equals 60 watts

If an average of 6 hours of peak sun per day is available in an area, then the above solar panel can produce an average 360 watt hours of power per day; 60w times 6 hrs. = 360 watt-hours. Since the intensity of sunlight contacting the solar panel varies throughout the day, we use the term "peak sun hours" as a method to smooth out the variations into a daily average. Early morning and late-in-the-day sunlight produces less power than the mid-day sun. Naturally, cloudy days will produce less power than bright sunny days as well. When planning a system your geographical area is rated in average peak sun hours per day based on yearly sun data. Average peak sun hours for various geographical areas is listed in the above section.

Solar panels can be wired in series or in parallel to increase voltage or amperage respectively, and they can be wired both in series and in parallel to increase both volts and amps. Series wiring refers to connecting the positive terminal of one panel to the negative terminal of another. The resulting outer positive and negative terminals will produce voltage the sum of the two panels, but the amperage stays the same as one panel. So two 12 volt/3.5 amp panels wired in series produces 24 volts at 3.5 amps. Four of these wired in series would produce 48 volts at 3.5 amps. Parallel wiring refers to connecting positive terminals to positive terminals and negative to negative. The result is that voltage stays the same, but amperage becomes the sum of the number of panels. So two 12 volt/3.5 amp panels wired in parallel would produce 12 volts at 7 amps. Four panels would produce 12 volts at 14 amps.

Series/parallel wiring refers to doing both of the above - increasing volts and amps to achieve the desired voltage as in 24 or 48 volt systems. The following diagram reflects this. In addition, the four panels below can then be wired in parallel to another four and so on to make a larger array.



Two 12v/3.5A panels in series and two in parallel. This doubles the voltage and doubles the amps to make 24 volts and 7 amps.

Charge Controller:

A charge controller monitors the battery's state-of-charge to insure that when the battery needs charge-current it gets it, and also insures the battery isn't over-charged. Connecting a solar panel to a battery without a regulator seriously risks damaging the battery and potentially causing a safety concern.

Charge controllers (or often called charge regulator) are rated based on the amount of amperage they can process from a solar array. If a controller is rated at 20 amps it means that you can connect up to 20 amps of solar panel output current to this one controller. The most advanced charge controllers utilize a charging principal referred to as Pulse-Width-Modulation (PWM) - which insures the most efficient battery charging and extends the life of the battery. Even more advanced controllers also include Maximum Power Point Tracking (MPPT) which maximizes the amount of current going into the battery from the solar array by lowering the panel's output voltage, which increases the charging amps to the battery - because if a panel can produce 60 watts with 17.2 volts and 3.5 amps, then if the voltage is lowered to say 14 volts then the amperage increases to 4.28 (14v X 4.28 amps = 60 watts) resulting in a 19% increase in charging amps for this example.

Many charge controllers also offer Low Voltage Disconnect (LVD) and Battery Temperature Compensation (BTC) as an optional feature. The LVD feature permits connecting loads to the LVD terminals which are then voltage sensitive. If the battery voltage drops too far the loads are disconnected - preventing potential damage to both the battery and the loads. BTC adjusts the charge rate based on the temperature of the battery since batteries are sensitive to temperature variations above and below about 75 F degrees.

Battery:

The Deep Cycle batteries used are designed to be discharged and then re-charged hundreds or thousands of times. These batteries are rated in Amp Hours (ah) - usually at 20 hours and 100 hours. Simply stated, amp hours refers to the amount of current - in amps - which can be supplied by the battery over the period of hours. For example, a 350ah battery could supply 17.5 continuous amps over 20 hours or 35 continuous amps for 10 hours. To quickly express the total watts potentially available in a 6 volt 360ah battery; 360ah times the nominal 6 volts equals 2160 watts or 2.16kWh (kilowatt-hours). Like solar panels, batteries are wired in series and/or parallel to increase voltage to the desired level and increase amp hours.

The battery should have sufficient amp hour capacity to supply needed power during the longest expected period "no sun" or extremely cloudy conditions. A lead-acid battery should be sized at least 20% larger than this amount. If there is a source of back-up power, such as a standby generator along with a battery charger, the battery bank does not have to be sized for worst case weather conditions.

The size of the battery bank required will depend on the storage capacity required, the maximum discharge rate, the maximum charge rate, and the minimum temperature at which the batteries will be used. During planning, all of these factors are looked at, and the one requiring the largest capacity will dictate the battery size.

One of the biggest mistakes made by those just starting out is not understanding the relationship between amps and amp-hour requirements of 120 volt AC items versus the effects on their DC low voltage batteries. For example, say you have a 24 volt nominal system and an inverter powering a load of 3 amps, 120VAC, which has a duty cycle of 4 hours per day. You would have a 12 amp hour load (3A X 4 hrs=12 ah). However, in order to determine the true drain on your batteries you have to divide your nominal battery voltage (24v) into the voltage of the load (120v), which is 5, and then multiply this times your 120vac amp hours (5 x 12 ah). So in this case the calculation would be 60 amp hours drained from your batteries - not the 12 ah. Another simple way is to take the total watt-hours of your 120VAC device and divide by nominal system voltage. Using the above example; 3 amps x 120 volts x 4 hours = 1440 watt-hours divided by 24 DC volts = 60 amp hours.

Lead-acid batteries are the most common in PV systems because their initial cost is lower and because they are readily available nearly everywhere in the world. There are many different sizes and designs of lead-acid batteries, but the most important designation is that they <u>are</u> deep cycle batteries. Lead-acid batteries are available in both wet-cell (requires maintenance) and sealed no-maintenance versions. AGM and Gel-cell deep-cycle batteries are also popular because they are maintenance free and they last a lot longer.

Using an Inverter:

An inverter is a device which changes DC power stored in a battery to standard 120/240 VAC electricity (also referred to as 110/220). Most solar power systems generate DC current which is stored in batteries. Nearly all lighting, appliances, motors, etc., are designed to use ac power, so it takes an inverter to make the switch from battery-stored DC to standard power (120 VAC, 60 Hz).

In an inverter, direct current (DC) is switched back and forth to produce alternating current (AC). Then it is transformed, filtered, stepped, etc. to get it to an acceptable output waveform. The more processing, the cleaner and quieter the output, but the lower the efficiency of the conversion. The goal becomes to produce a waveform that is acceptable to all loads without sacrificing too much power into the conversion process.

Inverters come in two basic output designs - sine wave and modified sine wave. Most 120VAC devices can use the modified sine wave, but there are some notable exceptions. Devices such as laser printers which use triacs and/or silicon controlled rectifiers are damaged when provided mod-sine wave power. Motors and power supplies usually run warmer and less efficiently on mod-sine wave power. Some things, like fans, amplifiers, and cheap fluorescent lights, give off an audible buzz on modified sine wave power. However, modified sine wave inverters make the conversion from DC to AC very efficiently. They are relatively inexpensive, and many of the electrical devices we use every day work fine on them.

Sine wave inverters can virtually operate anything. Your utility company provides sine wave power, so a sine wave inverter is equal to or even better than utility supplied power. A sine wave inverter can "clean up" utility or generator supplied power because of its internal processing.

Inverters are made with various internal features and many permit external equipment interface. Common internal features are internal battery chargers which can rapidly charge batteries when an AC source such as a generator or utility power is connected to the inverter's INPUT terminals. Auto-transfer switching is also a common internal feature which enables switching from either one AC

source to another and/or from utility power to inverter power for designated loads. Battery temperature compensation, internal relays to control loads, automatic remote generator starting/stopping and many other programmable features are available.
Most inverters produce 120VAC, but can be equipped with a step-up transformer to produce 120/240VAC. Some inverters can be series or parallel "stacked-interfaced" to produce 120/240VAC or to increase the available amperage.

Efficiency Losses:

In all systems there are losses due to such things as voltage losses as the electricity is carried across the wires, batteries and inverters not being 100 percent efficient, and other factors. These efficiency losses vary from component to component, and from system to system and can be as high as 25 percent. That's why it's a good idea to speak to someone who has extensive design experience - like us! - to properly configure the right equipment for you.

Determining your solar power requirements and planning the number of components.

Important Initial Considerations

The following information is a general guide for sizing, *but not intended for more critical applications or remote sites requiring very high reliability.* These types of systems require extensive analysis of regional climate history, site specific data, expert understanding and selection of system components and should be designed by professionals. For example, among other things we use highly proprietary performance analysis software and climate histories of 30 or more years when planning for applications requiring very high or no-fail reliability.

GENERAL SIZING FOR SOLAR POWER

In sizing an electric system using solar power the first two factors we consider are the sunlight levels (insolation values) from your area and the daily power consumption of your electrical loads. Orientation of a solar array is best at true south. True south is slightly different than a magnetic reference or compass south. The more an array is situated off of true south the less the total insolation value. A quick way to determine solar south is to divide the span of time between sunrise and sunset in half. The position of the sun at the resulting time would be true solar south.

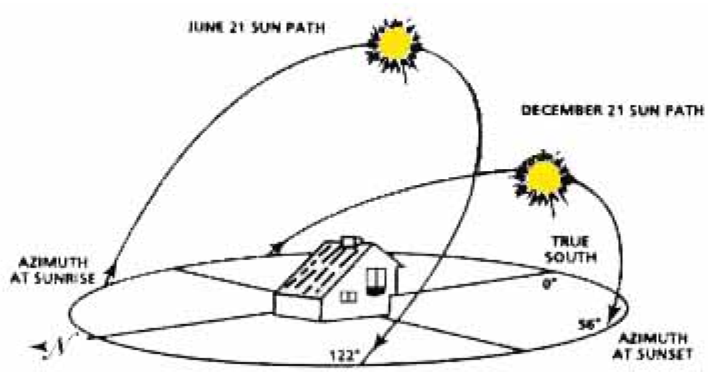
The angle of the solar array can be anywhere from your latitude plus 15 degrees to latitude minus 15 degrees for a yearly fixed mount position. Your latitude offers the best year-round position. By biasing the array "latitude plus 15 degrees" you will get slightly more insolation during winter months. A "latitude minus 15 degrees" will bias the array to summer months.

Insolation

Insolation, or sunlight intensity is measured in equivalent full sun hours. One hour of maximum, or 100% sunshine received by a solar panel equals one equivalent full sun hour. Even though the sun may be above the horizon for 14 hours a day, this may only result in six hours of equivalent full sun. There are two main reasons. One is reflection due to a high angle of the sun in relationship to your solar array. The second is also due to the high angle and the amount of the earth's atmosphere the light is passing through. When the sun is straight overhead the light is passing through the least amount of atmosphere. Early or late in the day the sunlight is passing through much more of the atmosphere due to its position in the sky. Sun tracking devices are available and can help reduce reflectance, but cannot help with the increased atmosphere in the sun's path.

Because of these factors the most productive hours of sunlight are from 9:00 a.m. to 3:00 p.m. around solar noon (solar south). This is different than 12:00 noon. Before and after these times power is being produced, but at much lower levels. When we size solar panels for a solar power system, we take these equivalent full sun hour figures per day and average them over a given period. You can quickly refer to **Appendix 1**, and then come right back here. Just close the new window that appears.

In most locations in the United States winter produces the least sunlight because of shorter days and increased cloud cover, as well as the sun's lower position in the sky. Usually, we work with a yearly average, a June - July average when insolation is highest, and a December - January average when insolation is lowest.



The diagram above illustrates the path of the sun over varying seasons. Remember when selecting a site for your solar power panels to pick a spot that is clear of shade from a minimum of 10 A.M. to 2 P.M. on December 21st. Even a limb from a deciduous tree will substantially reduce power output.

Many solar sites are quite uncomplicated in terms of shading and aspect. You may already have a good idea of where the sun appears in the morning and disappears in the evening, as well as how low it swings in the winter sky. If your site is partially shaded, it may be necessary to determine exactly where the best placement of solar panels will be. If you need a more sophisticated site analysis, please contact us. We also have world-wide insolation data as well as more local data that can be useful for your particular location.

Nominal DC System Voltage

Since solar panels charge your battery and these are both typically low voltage DC items, it's best to decide up-front what your nominal DC voltage will be. The decision of which DC voltage to use is often dictated by the distance between the various components. For example, with solar panels wired at 12 volts charging a 12 volt battery it is difficult to "push" the 12 volts very far, so if the solar array is going to be more than 75 -100 feet from the batteries it would be advisable to have 24 volt nominal charging since 24 volts will push farther than 12 volts over the same wire size. Rather than increase the wire size to the thickness of your thumb as in a AWG#0000 (4 ought) cable to carry the 12 volts efficiently, it's usually advisable to use 24 or 48 volts and keep the wire sizes between components much smaller. For further reference click the link below or contact us for assistance.

Calculate your AC and DC loads.

List wattage and hours of use per week (or other period) for all loads in the spaces provided. Multiply Watts by Hours/Week to get Watt-Hours per Week (WH/Wk.) for each load. Then add up all the watt hours per week to determine total Watt Hours Per Week. For total home systems that have a grid-connected electrical history you can simply use the kWh per month from your bill and convert this into a weekly figure, where the monthly kWh (X) divided by 4.3 times 1000 equals your average weekly watt-hours per week.

The form requests weekly totals, but you can change weekly watt-hours to daily or any period which applies to your particular situation by simply modifying the time period that you're working with...as long as you establish Ah/day in Line #10.

Note: Wattage of appliances can usually be determined from tags on the back of the appliance or from the owner's manual. If an item is rated in amps, multiply amps by operating voltage to find the watts. Another way to more accurately calculate your AC loads is to use a power meter. We sell various power meters that simply "plug in" and you read the actual wattage. These are very handy for planning a solar power electric system, but also very useful to have around after you get your system up and running. These power meters start at $99, but can often save you by more accurately calculating your actual loads for specific items. Contact us for more information on the power meter.

INVERTER SELECTION

Inverters are rated in continuous wattage and surge watts. Continuous watts is the total watts the inverter can support indefinitely. So a 4000 watt inverter can power up to 4000 watts continuously. Surge watts is how much power the inverter can support for a very brief period, usually momentary. So a 4000 watt inverter rated at 7000 surge watts can handle up to 7000 watts momentarily while starting such loads as motors - which usually require more than normal power to get started.

To select the appropriate inverter size, refer back to the LOAD CALCULATION WORK FORM and add up the wattage of your specific items which will (or potentially can) operate simultaneously to determine the minimum continuous watts you need. Then, also look at the potential surge of the specific items to determine the minimum surge wattage you'll need. Usually, you'll need 1.5 to 2 times the continuous rating. Some deep well submersible pumps can require 3 times the surge protection. We can assist you with this if you have any problems determining either continuous or surge requirements.
Finally, if any of your specific items operate at 220-240 volts you'll need either a step-up transformer - which will also give you the 220-240 volts for one or more items, or you can "stack-interface" two inverters to produce both 120 and 240 volts. We can assist you with this if you're not sure which way is better for you.

Solar Array Sizing

To find average sun hours per day in your area (line 3), check local weather data, or go to the Solar Energy Maps page. If you want year-round reliability, it's best to use the lowest of the figures or "smooth" the data. The peak amperage of the module you will be using can be found in the module specifications. You can also get close enough for this basic understanding if you divide the modules wattage by the peak power point voltage, usually 17 to 18.5.

Battery Size

All lead-acid batteries have a nominal output of 2 volts per cell. Actual cell voltage varies from about 1.7 volts at full discharge to 2.4 volts at full charge. 12 volt lead-acid batteries are made of 6 separate cells in one case. 6 volt batteries are made of 3 cells in one case. Industrial 2 volt single-cell batteries are also used in a series for larger applications. Series connections are where the positive terminal of one battery is connected to the negative terminal of another, resulting in increased voltage. Putting battery cells in parallel (positive to positive and negative to negative) increases (amps) amp-hour capacity, but does not affect voltage.

The size of the battery bank required will depend on the storage capacity required, the maximum discharge rate, the maximum charge rate, and the minimum temperature at which the batteries will be used. When designing a power system, all of these factors are looked at, and the one requiring the largest capacity will dictate battery size. Our System Sizing work forms take many of these factors into account.

One of the biggest mistakes made by those just starting out is not understanding the relationship between amps and amp-hour requirements of 120 volt AC items versus the effects on their DC low voltage batteries. For example, say you have a 24 volt nominal system powering a load of 3 amps, 120VAC, which has a duty cycle of 4 hours per day. You would have a 12 amp hour load (3A X 4 hrs=12 ah). However, in order to determine the true drain on your batteries you have to divide your nominal battery voltage (24v) into the voltage of the load (120v), which is **5**, and then multiply this times your amp hours (12 ah). So in this case the calculation would be **60 amp hours** drained from your batteries - not the 12 ah. The easiest way to quickly determine the total battery amp hours required is to first determine total watt-hours required by all loads, and then divide by the nominal DC system voltage. This resulting number will indicate the amount of amp hours needed to operate all loads for a given period. However, additional amp hour capacity would typically be added for more "reserve" capacity or to prevent complete discharge. Using the above example, 3 amps x 120 VAC x 4 hours = 1440 watt-hours divided by 24 VDC battery environment equals **60 amp-hours**; the same answer as before, but another way to get it.

There are other factors for determining the full extent of the battery drain, such as temperature, start-up factors, etc., but this should help you get a more complete picture on how to size your low DC voltage batteries when powering 120/240 volt loads using an inverter. Our System Sizing work forms take many of these factors into account.

Temperature has a significant effect on lead-acid batteries. At 40°F they will have about 75% of rated capacity, and at 0°F their capacity drops to about 50%. An exception to this general rule would be the **Concorde** PVX battery, which is not as sensitive to these temperature extremes.

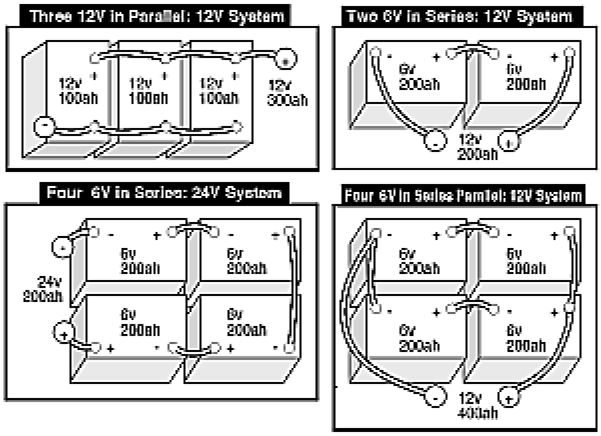
The storage capacity of a battery, the amount of electrical energy it can hold, is usually expressed in amp hours. If one amp is used for 100 hours, then 100 amp-hours have been used. A battery in a solar power system should have sufficient amp hour capacity to supply needed power during the longest expected period "no sun" or extremely cloudy conditions. In wind systems allowance for "no wind" days should be included. A lead-battery should be sized at least 20% larger than this amount. If there is a source of back-up power, such as a standby generator along with a battery charger, the battery bank does not have to be sized for worst-case weather conditions.

Series Wiring

Series wiring refers to connecting batteries to increase volts, but not amps. If you have two 6 volt batteries like the Trojan L16 rated at 350 amp hours, for example, by connecting the positive terminal of one battery to the negative terminal of the other, then you have series wired the two together. In this case, you now have a 12 volt battery and the rated 350 amps does not change. If you were to series wire four L16's you'd have 24 volts at 350 amps, and so on.

Parallel Wiring

Parallel wiring refers to connecting batteries to increase amps, but not volts. If you have two 6 volt batteries like the Trojan L16 rated at 350 amp hours, for example, by connecting the positive terminal of one battery to the positive terminal of the other, and the same with the negative terminal, then you have parallel wired the two together. In this case, you now have a 6 volt battery and the rated 350 amps increases to 700 amp hours. If you were to series wire four L16's you'd have 24 volts at 350 amps, and then parallel wire these four to the four other that are in series, then you'd have a 24 volt battery at 700 amps.



Using these wiring examples a complete battery bank might have any number of total batteries to achieve required reserve capacity.

Five basic wiring types

Lead-Acid Batteries

Lead-acid batteries are the most common in PV systems because their initial cost is lower and because they are readily available nearly everywhere in the world. There are many different sizes and designs of lead-acid batteries, but the most important designation is whether they are deep cycle batteries or shallow cycle batteries.

Shallow cycle batteries, like the type used as starting batteries in automobiles, are designed to supply a large amount of current for a short time and stand mild overcharge without losing electrolyte. Unfortunately, they cannot tolerate being deeply discharged. If they are repeatedly discharged more than 20 percent, their life will be very short. These batteries are not a good choice for a PV system.

Deep cycle batteries are designed to be repeatedly discharged by as much as 80 percent of their capacity so they are a good choice for power systems. Even though they are designed to withstand deep cycling, these batteries will have a longer life if the cycles are shallower. All lead-acid batteries will fail prematurely if they are not recharged completely after each cycle. Letting a lead-acid battery stay in a discharged condition for many days at a time will cause sulfation of the positive plate and a permanent loss of capacity.

Sealed deep-cycle lead-acid batteries are maintenance free. They never need watering or an equalization charge. They cannot freeze or spill, so they can be mounted in any position. We especially recommend sealed batteries for remote, unattended power systems, but also for any client who wants the maintenance free feature and doesn't mind the extra cost associated with these batteries. The **Concorde** PVX series (Sun-Xtender) is an excellent choice.

Sealed Gel Cell (gelled-electrolyte) batteries are relatively maintenance free, however unlike a high quality sealed lead-acid battery like the Concorde PVX extra care must be taken to insure a Gel Cell battery is not charged above 14.1 volts for a 12 volt battery, for example. Over charging a Gel Cell even once for a sustained period can really shorten it's life and even ruin it. Any charge source or charge regulator used must have user adjustable settings for sealed Gel Cell batteries to insure charge voltage does not exceed a safe limit. If your application dictates a sealed, gelled battery the Deka-East Penn **MK** series is an excellent choice.

Caring For Wet Cell Lead-Acid Batteries

Wet cell lead acid batteries like the high quality **Surrette** require periodic watering and equalization. Always use extreme caution when handling batteries and electrolyte. Wear gloves, goggles and old clothes. "Battery acid" will burn skin and eyes and destroy cotton and wool clothing.

The quickest way to ruin lead-acid batteries is to discharge them deeply and leave them stand "dead" for an extended period of time. When they discharge, there is a chemical change in the positive plates of the battery. They change from lead oxide when charged to lead sulfate when discharged. If they remain in the lead sulfate state for a few days, some part of the plate does not return to lead oxide when the battery is recharged. If the battery remains discharged longer, a greater amount of the positive plate will remain lead sulfate. The parts of the plates that become "sulfated" no longer store energy. Batteries that are deeply discharged, and then charged partially on a regular basis can fail in less than one year.

Check your batteries on a regular basis to be sure they are getting charged. Use a hydrometer to check the specific gravity of your lead acid batteries. If batteries are cycled very deeply and then recharged quickly, the specific gravity reading will be lower than it should because the electrolyte at the top of the battery may not have mixed with the "charged" electrolyte. Check the electrolyte level in wet-cell batteries at least four times a year and top each cell off with distilled water. Do not add water to discharged batteries. Electrolyte is absorbed when batteries are very discharged. If you add water at this time, and then recharge the battery, electrolyte will overflow and make a mess.

Keep the tops of your batteries clean and check that cables are tight. Do not tighten or remove cables while charging or discharging. Any spark around batteries can cause a hydrogen explosion inside and ruin one of the cells, and possibly you too.

It is a good idea to do an equalizing charge when some cells show a variation of 0.05 specific gravity from each other. This is a long steady overcharge, bringing the battery to a gassing or bubbling state. Typically, we'll recommend an equalization charge at least once a month. Do not equalize sealed or gell type batteries. With proper care, lead-acid batteries will have a long service life and work very well in almost any power system.

Measuring battery condition

Connect a voltmeter and measure the voltage across the battery terminals with the battery at rest (no input, no output) for at least three hours. These readings are best taken in the early morning, at or before sunrise, or in late evening. Take the reading while all loads are off and no charging sources are producing power.
The following table will allow conversion of the voltage readings obtained to an estimate of state of charge. The table is good for batteries at 77·F that have been at rest for 3 hours or more. If the batteries are at a lower temperature you can expect lower voltage readings.

Battery State of Charge Voltage Table

Percent of Full Charge	12 Volt DC System	24 Volt DC System	48 Volts DC System
100%	12.7	25.4	50.8
90%	12.6	25.2	50.4
80%	12.5	25	50
70%	12.3	24.6	49.2
60%	12.2	24.4	48.8
50%	12.1	24.2	48.4
40%	**12.0**	**24**	**48**
30%	11.8	23.6	47.2
20%	11.7	23.4	46.8
10%	11.6	23.2	46.4

0%	<11.6	<23.2	<46.4

The following chart reflects state of charge vs. specific gravity of the electrolyte in each cell. A hydrometer is used to determine specific gravity.

State of Charge	**Specific Gravity**
100% Charged	1.265
75% Charged	1.239
50% Charged	1.200
25% Charged	1.170
Fully Discharged	1.110
These readings are correct at 75°F	

Appendix

2% Voltage Drop Chart For 12 volt Systems

Maximum distance in feet of various gauge two conductor copper wire from power source to load for 2% voltage drop in a 12 volt system. Do not exceed the 2% drop for wire between PV modules and batteries. A 4 to 5% loss is acceptable between batteries and lighting circuits in most cases, however the cost of the next larger wire size is usually insignificant and increases efficiency.

Amps	#14	#12	#10	#8	#6	#4	#2	#1/0	#2/0	#4/0
1	45	70	115	180	290	456	720	.	.	.
2	22.5	35	57.5	90	145	228	360	580	720	1060
4	10	17.5	27.5	45	72.5	114	180	290	360	580
6	7.5	12	17.5	30	47.5	75	120	193	243	380
8	5.5	8.5	11.5	22.5	35.5	57	90	145	180	290
10	4.5	7	11.5	18	28.5	45.5	72.5	115	145	230
15	3	4.5	7	12	19	30	48	76.5	96	150
20	2	3.5	5.5	9	14.5	22.5	36	57.5	72.5	116
25	1.8	2.8	4.5	7	11.5	18	29	46	58	92
30	1.5	2.4	3.5	6	9.5	15	24	38.5	48.5	77
40	.	.	2.8	4.5	7	11.5	18	29	36	56
50	.	.	2.3	3.6	5.5	9	14.5	23	29	46
100	.	.	.	.	2.9	4.6	7.2	11.5	14.5	23
150	.	.	.	.	.	.	4.8	7.7	9.7	15
200	.	.	.	.	.	.	3.6	5.8	7.3	11

Load Calculation Work Form

This worksheet determines the total amp hours per day used by all the AC and DC loads in your system.

Helpful Formulas: Watts = Volts times Amps; Amps = Watts divided by Volts

Step 1 Calculate your AC loads. If there are no AC loads, skip to Step 2.

Description of AC Loads Run by an inverter	Watts	X	Hrs/Wk	=	WH/Wk
		X		=	
		X		=	
		X		=	
		X		=	
		X		=	
		X		=	
		X		=	
		X		=	
line 1 -->			Total WH/Wk		

2. Multiply line 1 by 1.25 to correct for inverter loss and battery efficiency.

3. Inverter DC input voltage; usually 12, 24 or 48 volts. This is DC system voltage.

4. Divide line 2 by line 3. This is total amp hours per week used by AC loads.

Step 2 Calculate your DC loads.
5. List all DC loads in the spaces below.

Description of DC Loads	Watts	X	Hrs/Wk	=	WH/Wk
		X		=	
		X		=	
		X		=	
		X		=	
		X		=	
		X		=	
		X		=	
		X		=	
line 5 -->			Total WH/Wk		

6. DC system voltage. Usually 12, 24 or 48 volts.

7. Total amp hours per week used by DC loads. Divide line 5 by line 6.

8. Total amp hours per week used by AC loads from line 4

9. Add lines 7 and 8. This is total amp hours per week used by all loads.

10. Divide line 9 by 7 days. This is total average amp hours per day.

Solarisation Chart

State	City	High	Low	Avg
AK	Fairbanks	5.87	2.12	3.99
AK	Matanuska	5.24	1.74	3.55
AL	Montgomery	4.69	3.37	4.23
AR	Bethel	6.29	2.37	3.81
AR	Little Rock	5.29	3.88	4.69
AZ	Tuscon	7.42	6.01	6.57
AZ	Page	7.30	5.65	6.36
AZ	Pheonix	7.13	5.78	6.58

CA	Santa Maria	6.52	5.42	5.94
CA	Riverside	6.35	5.35	5.87
State	City	High	Low	Avg
CA	Davis	6.09	3.31	5.10
CA	Fresno	6.19	3.42	5.38
CA	Los Angeles	6.14	5.03	5.62
CA	Soda Springs	6.47	4.40	5.60
CA	La Jolla	5.24	4.29	4.77
CA	Inyokern	8.70	6.87	7.66
CO	Grandby	7.47	5.15	5.69
CO	Grand Lake	5.86	3.56	5.08
CO	Grand Junction	6.34	5.23	5.85
CO	Boulder	5.72	4.44	4.87
DC	Washington	4.69	3.37	4.23
State	City	High	Low	Avg
FL	Apalachicola	5.98	4.92	5.49
FL	Belie Is.	5.31	4.58	4.99
FL	Miami	6.26	5.05	5.62
FL	Gainsville	5.81	4.71	5.27
FL	Tampa	6.16	5.26	5.67
GA	Atlanta	5.16	4.09	4.74
GA	Griffin	5.41	4.26	4.99
HI	Honolulu	6.71	5.59	6.02
IA	Ames	4.80	3.73	4.40
ID	Boise	5.83	3.33	4.92
ID	Twin Falls	5.42	3.42	4.70
IL	Chicago	4.08	1.47	3.14
IN	Indianapolis	5.02	2.55	4.21
KS	Manhattan	5.08	3.62	4.57
KS	Dodge City	4.14	5.28	5.79

KY	Lexington	5.97	3.60	4.94
LA	Lake Charles	5.73	4.29	4.93
LA	New Orleans	5.71	3.63	4.92
LA	Shreveport	4.99	3.87	4.63
MA	E. Wareham	4.48	3.06	3.99
State	City	High	Low	Avg
MA	Boston	4.27	2.99	3.84
MA	Blue Hill	4.38	3.33	4.05
MA	Natick	4.62	3.09	4.10
MA	Lynn	4.60	2.33	3.79
MD	Silver Hill	4.71	3.84	4.47
ME	Caribou	5.62	2.57	4.19
ME	Portland	5.23	3.56	4.51
MI	Sault Ste. Marie	4.83	2.33	4.20
MI	E. Lansing	4.71	2.70	4.00
MN	St. Cloud	5.43	3.53	4.53
MO	Columbia	5.50	3.97	4.73
MO	St. Louis	4.87	3.24	4.38
MS	Meridian	4.86	3.64	4.43
MT	Glasgow	5.97	4.09	5.15
MT	Great Falls	5.70	3.66	4.93
MT	Summit	5.17	2.36	3.99
NM	Albuquerque	7.16	6.21	6.77
NB	Lincoln	5.40	4.38	4.79
NB	N. Omaha	5.28	4.26	4.90
NC	Cape Hatteras	5.81	4.69	5.31
NC	Greensboro	5.05	4.00	4.71
ND	Bismark	5.48	3.97	5.01
NJ	Sea Brook	4.76	3.20	4.21
NV	Las Vegas	7.13	5.84	6.41

NV	Ely	6.48	5.49	5.98
NY	Binghamton	3.93	1.62	3.16
NY	Ithaca	4.57	2.29	3.79
NY	Schenectady	3.92	2.53	3.55
NY	Rochester	4.22	1.58	3.31
NY	New York City	4.97	3.03	4.08
OH	Columbus	5.26	2.66	4.15
OH	Cleveland	4.79	2.69	3.94
State	City	High	Low	Avg
OK	Stillwater	5.52	4.22	4.99
OK	Oklahoma City	6.26	4.98	5.59
OR	Astoria	4.76	1.99	3.72
OR	Corvallis	5.71	1.90	4.03
OR	Medford	5.84	2.02	4.51
PA	Pittsburg	4.19	1.45	3.28
PA	State College	4.44	2.79	3.91
RI	Newport	4.69	3.58	4.23
SC	Charleston	5.72	4.23	5.06
SD	Rapid City	5.91	4.56	5.23
TN	Nashville	5.20	3.14	4.45
TN	Oak Ridge	5.06	3.22	4.37
TX	San Antonio	5.88	4.65	5.30
TX	Brownsville	5.49	4.42	4.92
TX	El Paso	7.42	5.87	6.72
TX	Midland	6.33	5.23	5.83
TX	Fort Worth	6.00	4.80	5.43
UT	Salt Lake City	6.09	3.78	5.26
UT	Flaming Gorge	6.63	5.48	5.83
VA	Richmond	4.50	3.37	4.13
WA	Seattle	4.83	1.60	3.57

WA	Richland	6.13	2.01	4.44
WA	Pullman	6.07	2.90	4.73
WA	Spokane	5.53	1.16	4.48
WA	Prosser	6.21	3.06	5.03
WI	Madison	4.85	3.28	4.29
WV	Charleston	4.12	2.47	3.65
WY	Lander	6.81	5.50	6.06

Inverter Terminology

<u>Absorption Charge</u> - The second stage of three-stage battery charging. Voltage remains constant and current tapers as internal battery resistance increases during charging. (Ensures complete charging.)

<u>Alternating Current (AC)</u> - The type of electrical power supplied by utilities or made when a generator is run. The unique characteristic of this form of electricity is that it reverses direction at regular intervals. For example, 120 Vac 60 Hz. power reverses flow 60 times a second, hence the rating 60 Hz. (cycles).

Amp - A measurement of the flow of electrical current. One amp is equal to the electric force of one volt acting across the resistance of one ohm.

Amp Hour - One amp of electrical current flowing for one hour. Expresses the relationship between current (amps) and time. (OHMS law I =V/R**)**

Array - A group of solar electric modules wired together.

Bulk Charge - The first stage of three-stage battery charging. Current is sent to batteries at the maximum rate they will accept while voltage rises to full charge level.

Current - The rate of flow of electrical charge. The flow of amps is often expressed as current.

Direct Current (DC) - The type of electricity stored in batteries and generated by solar electric devices. Current flows in a single direction.

Electrolyte - A conductive medium in which the flow of electricity takes place; this is the liquid found inside storage batteries.

Float Charge - The third stage of three-stage battery charging. After batteries reach full charge, charging voltage is reduced to a lower level to reduce gassing (boiling of electrolyte) and prolong battery life. This is often referred to as a maintenance charge, since rather than charging a battery, it keeps an already-charged battery from self-discharging.

Grid - When used in reference to utility power, it refers to a system of electrical transmission and distribution lines.

Grid Open - The inverter (Trace SW) can tell when there is no current being delivered to the grid and it will disconnect. This is used when a disconnected switch is opened or the power line which feeds the installation is cut. This protective system may require up to one second to respond.

Grid Shorted - Normally, when the utility power fails, the Trace SW inverter momentarily tries to power the entire neighborhood. This condition looks like a short circuit to the inverter and causes it to reach the over-current protection setting and shuts off. It then opens it internal relay and disconnects from the utility grid. This protective system operates instantly (under four milliseconds).

Ground Fault Protection (GFP) - A circuit protection device that prevents the flow of electrical current to earth if a short circuit is present. Usually required in wet locations-e.g. for outdoor, kitchen and bathroom circuits.

Hertz (Hz.) - The frequency, or number of times per second, that the flow of AC electricity reverses itself. Also referred to as cycles (see alternating current).

High Battery Protection - A control circuit that disconnects charge current flowing to a battery when voltage reaches a dangerously high threshold. Prevents damage created by excess gassing (or boiling) of electrolyte.

Hydrometer - A simple device that measures the specific gravity of battery electrolyte. Specific gravity readings express state of charge/discharge of battery.

Idle Current - The amount of electrical power required to keep an inverter ready to produce electricity on demand.

Islanding - This occurs when the grid has failed and the "neighborhood" that the Trace SW inverter is powering requires the same amount of power that the inverter can supply. This balanced condition is often called "islanding". The islanding detection circuit checks the grid condition on each cycle. The inverter watches the utility grid and waits for it to rise a couple of volts before it begins to invert again. This is done on each cycle when SELL mode is activated. Typically, disconnection is achieved in a few cycles after the utility has failed. If a large electric motor is connected, it may provide enough generator capacity that the inverter thinks the grid is still connected. This can fool this protective system. Two additional protective systems are provided to then handle this condition over/under frequency and over/under voltage detection.

Kilowatt (kW) - One thousand watts of electricity. Ten 100-watt light bulbs use one Kilowatt of electrical power.

Kilowatt hour (kWh) - One kW of electrical power used for one hour. The most common measurement of electrical consumption, most grid connected electrical meters measure kWh for billing purposes.

Light Emitting Diode (LED) - A device used to display various status functions.

Line Loss - A voltage drop caused by resistance in wire during transmission of electrical power over distance.

Line-tie - An electrical system that is connected to a utility distribution grid. For example, Trace SW line-tie inverters are designed to connect to and interact with utility power.
Load - Any device that consumes electricity in order to operate. Appliances, tools, and lights are examples of electrical loads.

Low Battery Protection - A control circuit that stops the flow of electricity from batteries to loads when battery voltage drops to dangerously low levels.

Maximum Power Point Tracking (MPPT) - Every PV (solar electric) device has a point where maximum current is delivered. MPPT electronically adjusts the output PV-device output to the maximum power point.

Modified Sine Wave - An AC wave form (generated by many inverters) that is a pulse width modified square wave. It consists of a number of very small on/off steps rather than a fully smooth wave.

National Electric Code - A consistent set of electrical wiring and installation standards used in the United States.

Off Grid - An electrical system that is not connected to a utility distribution grid.

Oscilloscope - A device that displays the wave form created by an electrical generating device such as a generator, inverter, or utility.

Overload/Over-current Protection - A control circuit designed to protect an inverter or similar device from loads exceeding its output capacity. (A fuse, for example, is an over-current protection device.) All Trace inverters have internal circuitry to protect themselves from overload/over-current conditions.

Over/Under Frequency - Since the Trace SW inverter locked onto the frequency of the "Islanded" utility grid, the frequency of the system will drift out of regulation in a short amount of time during an islanding condition. This protective system may require up to one second to respond. The inverter will shut off and disconnect after the frequency exceeds +/- 1 hertz of the nominal frequency.

Over/Under Voltage - Since the Trace SW inverter does not regulate the voltage of the utility grid while selling power into it, the AC voltage will drift out of regulation in a short amount of time during an islanding condition. This protective system may require up to one second to respond. The inverter will shut off and disconnect after the voltage exceeds +/- 10% of the nominal AC voltage.

Parallel Wiring - A group of electrical devices, such as batteries or PV modules, wired together to increase ampacity, while voltage remains constant. (Two 100 amp hour 12 Vdc batteries wired in parallel will form a 200 amp-hour 12 Vdc battery bank.)

Photovoltaic System - The components that form a solar electric generating system, usually consisting of PV modules, charge controller, circuit protectors (fuses or breakers) and batteries.

Series Wiring - A group of electrical devices, such as batteries or PV modules, wired together to increase voltage, while ampacity remains constant. (Two 100 amp hour 12 Vdc batteries wired in series form a 100 amp hour 24 Vdc battery bank.)

Sine Wave - The output wave form of an electric generator or utility. A smooth wave going above and below zero is created. This wave form is also produced by sine wave inverters such as the Trace SW and CO-Sine series.

Surge Capacity - The amount of current an inverter can deliver for short periods of time. Most electric motors draw up to three times their rated current when starting. An inverter will "surge" to meet these motor-starting requirements. Most Trace inverters have surge capacities at least three times their continuous ratings.

Transfer Switch - A switch designed to transfer electricity being supplied to loads (appliances etc.) from one source of power to another. (A transfer switch may be used to designate whether power to a distribution panel will come from a generator or inverter.)

Volts - A unit of measure of the pressure in an electrical circuit. Volts are a measure of electric potential. Voltage is often explained using a liquid analogy- comparing water pressure to voltage: a high pressure hose would be considered high voltage, while a slow-moving stream could be compared to low voltage.

Watt(s) - A quantitative measurement of electrical power. Watts are calculated by multiplying volts times amps. Using a liquid analogy, watts are similar to liquid flow such as liters or gallons. (watts = volts x amps)

Watt Hour (wHr) - Electrical power measured in terms of time. One watt hour of electricity is equal to one watt of power being consumed for one hour. (A one-watt light operated for one hour would consume one watt hour of electricity.)

Solar Array Sizing Workform

This worksheet helps you figure the total number of solar modules required for your system. If you want year-round reliability, it's best to use the lowest of the figures or "smooth" the data. The peak amperage of the module you will be using can be found in the module specifications. You can also get close enough for this basic understanding if you divide the modules wattage by the peak power point voltage, usually (17 to 18.5).

1. Total average amp hours per day from the System Loads Workform, line 10.

2. Multiply line 1 by 1.2 to compensate for loss from battery charge/discharge.

3. Average sun hours per day in your area.

4. Divide line 2 by line 3. This is the total solar array amps required.

5. Optimum or peak amps of solar module used. See module specifications.

6. Total number of solar modules in parallel required. Divide line 4 by 5.

7. Round off to the next highest whole number.

8. Number of modules in each series string to provide DC Battery voltage:

DC Battery Voltage	# of Modules in Each Series String
12	1
24	2
48	4

9. Total number of solar modules required. Multiply line 7 by 8.

Battery Size Work Form

1. Total average amp hours per day from the System Loads Worksheet, line 10.

2. Maximum number of continuous cloudy days expected in your area.

3. Multiply line 1 by line 2.

4. Divide line 3 by (maximum) 0.8 to maintain a 20% reserve after deep discharge period.
To prevent less than a maximum 80% discharge divide by a lessor number in #4 above.

If no special conditions below apply, skip lines 5 through 9 and proceed to line 10.

Special Conditon #1: Heavy electrical load

5. Maximum amperage that will be drawn by the loads for 10 minutes or more.

6. Discharge rate of battery. If unknown, check with battery supplier.

7. Multiply line 5 by line 6.

Special condition #2: High Charge Current

8. Maximum output amperage of PV array or other battery charger.

9. Multiply line 8 by 10.0 hours.

10. Amp hours from line 4, 7, or 9, whichever is largest.

11. If you are using a lead-acid battery, select the multiplier below which corresponds to the battery's winter time average ambient temperature:

Battery Temperature	Multiplier
80°F/26.7°C	1.00
70°F/21.2°C	1.04
60°F/15.6°C	1.11
50°F/10.0°C	1.19
40°F/4.4°C	1.30
30°F/-1.1°C	1.40
20°F/-6.7°C	1.59

12. Multiply line 11 by line 10. This is your optimum battery size in amp-hours.

13. Amp-hours of battery chosen. (Example: Concorde 1040T = 104Ah/24 hrs. and 120Ah/120 hrs. etc.)
(Note: The faster the discharge the less total reserve amp-hour capacity)

14. Divide line 12 by line 13. This is the total number of batteries in parallel required.

15. Round off to the next highest whole number.